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GOES SOUNDER SINGLE FIELD OF VIEW PRODUCTS

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1. INTRODUCTION

The retrieval of atmospheric variables from GOES sounder measurements has occurred on an operational basis at the National Environmental Satellite, Data, and Information Service (NESDIS) on operational basis since 1995. The atmospheric variables are generated on an hourly basis over the Continental United States and adjacent waters and include: clear-sky radiances, profiles of temperature and moisture, layer precipitable water, cloud-top pressure, temperature, and effective cloud amount, surface skin temperature, and numerous atmospheric stability indices. The resolution of the current operational GOES sounder products is approximately 50km^2, with the exception of the cloud products, which are generated at full resolution (approximately 10km^2). The products are provided in a variety of formats, including ASCII (text), BUFR and Derived Product Imagery (DPI) that serve the needs of the National Weather Service (NWS) for Numerical Weather Prediction (NWP) and the Advanced Weather Interactive Processing System (AWIPS). Table 1 provides a summary of these GOES sounder products and their intended use by the NWS.

The advent of higher resolution NWP models and the need for higher resolution satellite products on AWIPS have led to new requirements for higher resolution GOES sounder products. In November 2005, NOAA/NESDIS will implement a new integrated GOES sounder product processing system into its operational environment that will produce all of the atmospheric products listed above at the full GOES sounder resolution (~10km^2). These Single-Field-Of-View (SFOV) retrieved products will continue to meet the quality and timeliness requirements specified by the NWS. They will offer provide better geographic coverage and improved depiction of gradient information than the current lower spatial resolution operational counterparts. Meeting product timeliness requirements, while processing up to 25 times more retrievals in clear sky conditions, was achieved through a significant amount of system redesign, together with the

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streamlining and development of the product system software. Meeting product quality requirements demanded a significant amount of attention to the cloud masking process and quality control.

GOES Sounder Product	Operational Use within the NWS
Clear-sky Radiances	Assimilation into NCEP operational regional & global NWP models
Layer & Total Precipitable Water	Assimilation into NCEP operational regional & global NWP models; display and animation within NWS AWIPS for use by forecasters at NWS WFOs & National Centers in forecasting precipitation and severe weather
Cloud-top retrievals (pressure, temperature, cloud amount)	Assimilation into NCEP operational regional & global NWP models; image display and animation within NWS AWIPS for use by forecasters at NWS WFOs; supplement to NWS/ASOS cloud measurements for generation of total cloud cover product at NWS/ASOS sites
Surface skin temperature	Image display and animation within NWS AWIPS for use by forecasters at NWS WFOs
Profiles of temp & moisture	Display (SKEW-Ts) within NWS AWIPS for use by forecasters at NWS WFOs in forecasting precipitation and severe weather
Atmospheric stability indices	Image display and animation within NWS AWIPS for use by forecasters at NWS WFOs in forecasting precipitation and severe weather

Table 1. NOAA/NESDIS Operational GOES Sounder Products and their operational use within the NWS

2. ALGORITHM DESCRIPTIONS

A non-linear physical retrieval algorithm (Ma et al, 1999) is employed to simultaneously retrieve atmospheric profiles of temperature and moisture, along with surface skin temperature. The algorithm employs a Newtonian iterative method that finds the maximum probability solution to the nonlinear inversion of the radiative transfer equation. The radiative transfer model used to calculate the GOES sounder channel radiances is based on the Pressure Layer Optical Depth (PLOD) or Pressure-layer Fast Algorithm for Atmospheric Transmittance (PFAAST) (Hannon et al, 1996). The first guess temperature and moisture profiles used in the retrieval step are obtained by a linear interpolation in time between two NCEP GFS forecasts that are valid less than 12 hours into the future, are separated by 3 hours, and bound the time of the GOES sounder imagery. Over land, the boundary layer of the first guess profiles are modified using an objective analysis of the surface reporting network for the most recent hour where a simple boundary level model is used to update estimates of surface air and skin temperature. Over ocean, the Sea Surface Temperature (SST) obtained from NCEP's Real-time Global Sea Surface

Temperature (RTG_SST) is used to modify the boundary layer of the first guess temperature and moisture profiles. In the absence of suspected low level inversions, the lowest 100 hPa of the first guess temperature and moisture profiles are blended with the surface data. Cases are flagged when convergence in the physical retrieval of temperature and moisture is not achieved and in cases where the temperature and/or moisture solutions depart too much from the first guess profiles.

For the retrieval of cloud top quantities, the CO_2 slicing algorithm (Chahine, 1974, Smith and Platt, 1978; Menzel et al, 1983) is one of two algorithms used and is the method of choice for retrieving the height and effective cloud amount for mid to high level non-opaque clouds. This is especially true for high, optically thin, cirrus clouds. The other method uses the longwave IR window channel brightness temperature, in conjunction with a collocated first guess temperature profile, to arrive at a cloud height solution. This method works reasonably well for opaque clouds, but not for optically thin clouds. This method is used when a CO_2 slicing solution cannot be obtained.

Prior to the retrieval of either atmospheric temperature/moisture profiles or cloud products, the measured radiances are corrected to remove the existence of suspected bias differences between these radiances and those computed from the NWP model-dependent first guess profiles. The bias differences can be due to a number of factors including: 1) instrument measurement error; 2) forward radiative transfer model errors that can originate from a number of sources including spectroscopic uncertainties and the numerical methods used to calculate the atmospheric transmittance spectra and spectral radiances; and 3) other processing errors that may include calibration, cloud detection and cloud clearing, and scene nonhomogeneity. This radiance bias tuning process is achieved via a regression method called “shrinkage estimation” (Crone et al, 1996).

Specification of the cloud mask for each GOES sounder Field-of-View (FOV) determines what atmospheric variables can and will be retrieved. This process is sometimes referred to as a “cloud-clearing” step, but in reality, it is a hole seeking exercise. Each FOV undergoes a multitude of tests which seek to identify the presence of cloud within the FOV. The longwave and shortwave IR window channels, the visible channel (during the daylight hours), and first guess skin temperatures from the boundary layer model (or SST) or derived from regression are relied on heavily to detect the presence of cloud within the FOV. Differences between the longwave and shortwave IR channel radiances are effective in detecting the presence of cirrus or the presence of very low cloud that may exist with the FOV. The existence of possible snow cover on the ground is considered in the process to avoid the false detection of cloud. The result of these tests is a cloud mask designation of either clear or cloudy.

If the FOV is determined to be clear, then retrievals of atmospheric profiles of temperature and moisture, along with skin temperature are attempted. Using these retrieved quantities, a number of atmospheric stability indices are computed. If the FOV is determined to be cloudy, then retrievals of cloud-top quantities that include pressure, temperature, and effective cloud amount (ECA) are computed. A “maybe cloudy” designation may be attached to a FOV if the cloud clearing step above indicates the presence of cloud, but the retrieved cloud amount is less than some predetermined lower limit. For these cases, the retrieved products are sent on to AWIPS for qualitative use, but will not be distributed to NCEP for use in NWP assimilation.

Refinements to the cloud clearing step are in progress in order to make it more robust. The refinements include calling the CO_2 slicing algorithm for every FOV in an attempt to identify the presence of thin cirrus that might otherwise be missed by the typical channel thresh-holding type tests that are being employed. It is expected that this will instill more confidence in the cloud mask produced and ultimately result in improvements to the quality of the products retrieved.

3. GOES PRODUCT RESULTS AND VALIDATION

The GOES sounder retrieved products are delivered to its primary user, the NWS, in a variety of formats depending on the intended use and application. Derived Product Imagery (DPI) are depictions of quantitatively derived meteorological information that are color-coded and displayed as images (Hayden et al, 1996). DPI is used in time-sequenced loops to animate changes in derived quantities such as atmospheric moisture, atmospheric stability, surface skin temperature, and cloud top height and amount. This time rate of change information is particularly important to forecasters. The current family of operational DPI products that get distributed to the NWS AWIPS include: Total Precipitable Water (TPW), Lifted Index (LI), Cloud-Top Pressure (CTP),

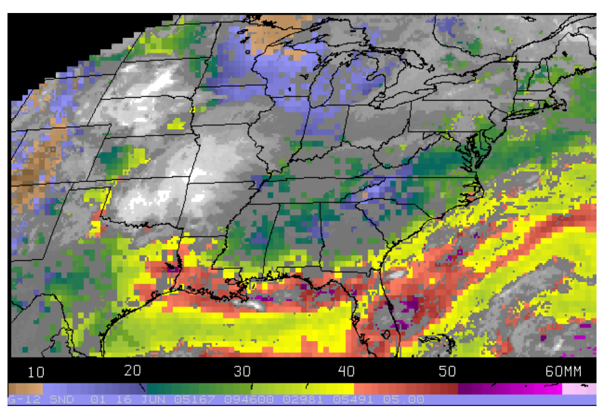

Figure 1. GOES-12 TPW Derived Product Image (DPI) at ~50km^2 resolution at 0946 UTC on 16 June 2005

and surface skin temperature. Figures 1 and 2 contrast the differences between the current operational GOES-12 TPW DPI product at $50km^2$ solution with the same product, but at

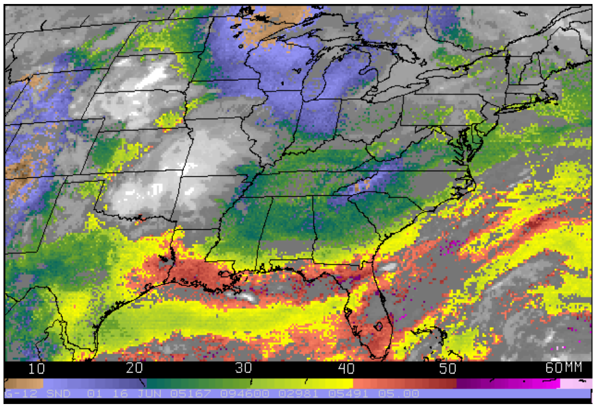

Figure 2. GOES-12 TPW Derived Product Image (DPI) at ~$10km^2$ resolution at 0946 UTC on 16 June 2005

~$10km^2$ resolution at 0946 UTC on 16 June 2005. The impact of the higher resolution is dramatic. Figures 3 and 4 illustrate yet another example of this, but for the DPI of Lifted Index (LI) from the afternoon (18 UTC 18 August, 2005) to early evening (03 UTC 19 August, 2005). The operational $50km^2$ LI DPI product is shown in Figure 3 and the new $10km^2$ LI DPI product is shown in Figure 4. The differences are dramatic. The SFOV product offers better coverage and improved depiction of gradient information than the current lower resolution $50km^2$ product. The SFOV products are successfully generated where small breaks in clouds occur. In areas such as these, the $50km^2$ products are generally not generated since a minimum number of clear FOVS in a 5x5 array of FOVS must exist in order to generate the product. The additional information and improved presentation of the SFOV data should prove to be more useful analysis tools for NWS forecasters in their warning decision making process. Weaver et al, 2002 make a strong case for this in a severe thunderstorm case study on 24 July 2000 during the GOES-11 science test where they utilized frequent interval GOES sounder imagery and SFOV DPI of Convective Available Potential Energy (CAPE) and Convective Inhibition (CIN). Through concurrent monitoring of imagery and/or DPI of atmospheric quantities such as moisture and stability, the forecaster may gain valuable insight into the near storm, pre-convective environment that may otherwise be unavailable.

The new SFOV DPI products will be the first set of products to replace the current operational $50km^2$ products on AWIPS. This switchover is scheduled to occur on 1 November 2005. Additional, real-time examples of SFOV GOES sounder DPI products can be found at: http://www.orbit.nesdis.noaa.gov/smcd/opdb/ goes/sdpi/html/sdpiimgnewt.html. A switchover to the to the new SFOV clear-sky radiances, precipitable water, and cloud-top products prepared for use within NWS/NCEP operational regional and global NWP data assimilation systems will occur after model impact assessments are completed through joint efforts with the Joint Center for Satellite Data Assimilation (JCSDA).

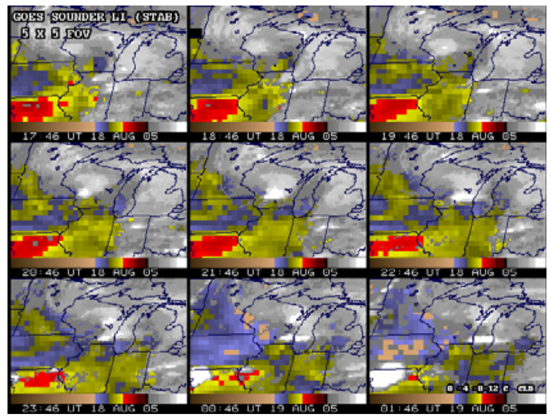

Figure 3. GOES-12 Lifted Index Derived Product Image at ~$50km^2$ resolution from approximately 18 UTC 18 Aug 2005 through 0200UTC 19 Aug 2005

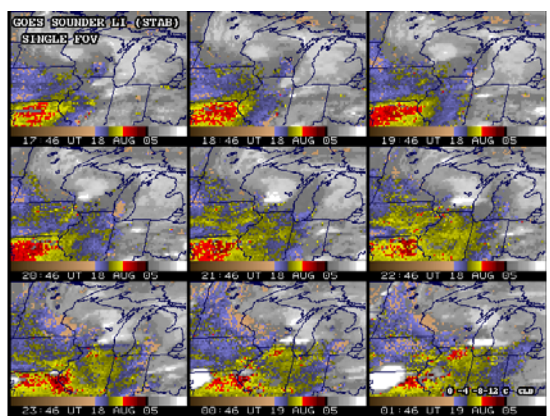

Figure 4. GOES-12 Lifted Index Derived Product Image at ~$10km^2$ resolution from approximately 18 UTC 18 Aug 2005 through approximately 0200 UTC 19 Aug 2005

GOES TPW retrievals are continuously validated against ground-based radiosonde observations of PW. Recent comparison statistics for GOES-12 and GOES-10 for the period 25 June 2005 – 29 Sept 2005 are summarized in Tables 2 and 3.

Ret-Raob Statistic	$50km^2$ PW Product	$10km^2$ PW Product
Bias (mm)	-1.01	0.84
RMSE (mm)	4.06	4.48
Correlation	0.95	0.94
Mean Retrieved PW (mm)	32.47	33.98
Mean Raob PW (mm)	33.48	33.14
Sample	11848	11651

Table 2. Comparison statistics between GOES-12 retrieved TPW and collocated radiosonde TPW for the period 25 June 2005 – 29 September 2005

The comparison statistics indicate that the quality of the $10km^2$ TPW retrievals are comparable in quality to the $50km^2$ TPW retrievals. This is as it should be. A couple of points are worth noting. First, in a mean sense, the SFOV $10km^2$ TPW retrievals tend to be more moist than their $50km^2$ TPW retrieval counterparts which tend to significantly underestimate the TPW amount. Second, the RMSE for the SFOV TPW retrievals tend to be slightly larger than the RMSE for the $50km^2$ TPW retrievals. These characteristics have been common features that we have observed over the course of developing and validating the SFOV PW product.

GOES-12 PW retrievals are also routinely being validated at the Department of Energy (DOE) Atmospheric Radiation Program (ARM) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site near Lamont, Oklahoma. Hourly comparisons between the GOES-12 SFOV PW retrievals and PW retrievals from the ground-based Microwave Radiometer (MWR) show good agreement. These comparisons are shown in Figure 5. This figure also includes the first guess TPW from a NWP model forecast and GOES-12 TPW retrievals derived from heritage versions of the GOES sounder retrieval algorithm. The 3x3 FOV (dark blue diamonds) TPW retrievals show possible evidence of contamination due to afternoon clouds, while the SFOV (yellow and light blue diamonds) TPW retrievals match the MWR data more closely.

Ret-Raob Statistic	$50km^2$ PW Product	$10km^2$ PW Product
Bias (mm)	-2.60	-0.36
RMSE (mm)	4.72	3.72
Correlation	0.90	0.91
Mean Retrieved PW (mm)	17.42	17.59
Mean Raob PW (mm)	20.02	17.95
Sample	1325	3892

Table 3. Comparison statistics between GOES-10 retrieved TPW and collocated radiosonde TPW for the period 25 June 2005 – 29 September 2005

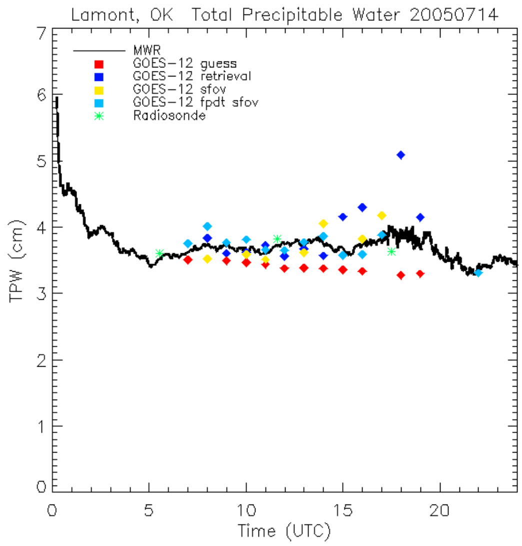

Figure 5. GOES-12 sounder TPW validations with a MWR at the Department of Energy – Atmospheric Radiation Program (DOE ARM) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site. Microwave radiometer (solid line), numerical model forecast (red diamonds), radiosonde (green asterisks) and GOES-12 physical retrieval of total precipitable water vapor values are compared near Lamont, Oklahoma on 14 July 2005.

5. SUMMARY AND CONCLUSIONS

In November 2005, NOAA/NESDIS will implement a new integrated GOES sounder product processing system into its operational environment that will produce the entire suite of GOES sounder products at full GOES sounder resolution (~$10km^2$). These higher resolution products offer better geographic coverage and improved depiction of gradient information than the current operational lower resolution counterparts. At the same time, the quality of these products, as judged by comparisons to radiosonde observations, are comparable to the quality of the lower resolution products. Just as important, the timeliness of these products is as good or better than the current operational products despite the fact that up to 25 times more data are processed. The lower resolution GOES sounder DPI products (TPW, LI, skin temperature, and cloud-top pressure) currently on AWIPS, are scheduled to be replaced by the new SFOV DPI equivalent products on 1 November 2005. These SFOV DPI products are expected to provide forecasters with additional insight into the near storm, pre-convective environment which should prove to be valuable to them in their warning decision making process. Replacement of the lower resolution GOES sounder products that are currently being assimilated within operational regional and global NWP data assimilation systems at NWS/NCEP, will occur after model impact assessments are completed through joint efforts with the JCSDA.

6. ACKNOWLEGDEMENTS

The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.

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